IDENTIFICATION OF OPERABLE UNIT NO. 3
AREA OF CONCERN
DRAFT REPORT

ROCKY FLATS PLANT

U.S. DEPARTMENT OF ENERGY
Rocky Flats Plant
Golden, Colorado

ENVIRONMENTAL RESTORATION PROGRAM

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LIST OF ACRONYMS

Am	Americium
AOC	Area of Concern
CDH	Colorado Department of Health
DOE	Department of Energy
E	Exponent, i.e., 1E-6 = 1.0×10^{-6} = 0.000001
EPA	Environmental Protection Agency
FS	Feasibility Study
LECR-M	Lifetime Excess Cancer Mortality Risks
MREM	Millirem
NCP	National Contingency Plan
OU	Operable Unit
pCi/g	pico Curie per gram
Pu	Plutonium
RCRA	Resource Conservation and Recovery Act
RFI	RCRA Facilities Investigation
RI	Remedial Investigation
RME	Reasonable Maximum Exposure

EXECUTIVE SUMMARY

This report identifies an area of concern (AOC) as requested by the United States Environmental Protection Agency (EPA) for Operable Unit No. 3 (OU 3) based on the presence of plutonium surface soil contamination. An AOC is a spatial location (i.e., area) where plutonium surface soil concentrations exceed levels that would be regarded as safe, based on judgements of acceptable risk. This draft report is subject to review and final approval by EPA.

The Department of Energy (DOE) has proposed preliminary risk-based soil reference activity concentrations that can be used to guide decisions regarding the use of OU 3 lands. These soil reference levels are based on EPA's risk range of 1E-6 to 1E-4 with a bias toward protection at the 1E-6 risk level (i.e., 1 in 1 million increase in lifetime cancer risk) which is the most conservative guidance of acceptable risk from EPA. Soil reference levels are proposed for two alternative land uses; recreational and residential.

The reference levels developed and presented in this report indicate no AOCs for recreational use within OU 3. In addition, the residential scenario AOC is confined to a small uninhabited area immediately adjacent to the RFP east boundary. A map identifies the OU 3 AOC.

The values presented in this report are preliminary and address only the risks arising from surface soils affected by plutonium and americium. A detailed study of other potential contaminants as well as an additional study of plutonium and americium contamination is being conducted at OU 3 under direction of the Interagency Agreement (IAG) between DOE, EPA, and the Colorado Department of Health (CDH).

This report contains the following sections:

- Section 1 presents introductory material.
- Section 2 discusses the methodology employed to arrive at surface soil activity concentrations.
- Section 3 presents the results of the assessment.
- Section 4 presents a discussion of results and conclusions.
- Appendix A includes risk related computational details and assumptions.
- Appendix B discusses surface soil data from OU 3 and statistical methods.
- Appendix C shows a plot of Pu^{239} surface soil activity concentrations and method logic discussion.
- Appendix D contains references.

1.0 INTRODUCTION

This report presents plutonium (Pu^{-239}) surface soil reference levels which are used in conjunction with a surface soil concentration map to identify an OU 3 offsite areas of concern (AOC). This work expands on two previously written reports: 1) the Generic Risk Assessment for exposure to Pu^{-239} contaminated soils reported in the Final Remedy Report (DOE, 1991), and 2) the October 1992 draft version of this report. Some reference levels reported in the October 1992 report contained minor computational errors. This report corrects those errors. This report also addresses comments received from the Environmental Protection Agency (EPA) on the October 1992 draft version of this report.

As reported in the Remedy Report (DOE, 1991), the Generic Risk Assessment for Exposure to Plutonium Contaminated Soils was of limited use. It was intentionally biased towards a conservative assessment on the side of safety. The Remedy Report suffered from a presentation that was conservatively biased and did not conform well to current risk analysis conventions and Agency guidance[1]. DOE has taken the opportunity with this report to refocus the OU 3 risk assessment process through revision of input parameters so that reference levels will more closely resemble a Reasonable Maximum Exposure (RME).

Several reference levels are developed in this report for both recreational and residential land use scenarios. A range of reference levels is presented to allow the risk manager flexibility in making land use decisions. The range of reference levels presented are based on very conservative RME assumptions to less conservative assumptions.

Surface soil reference levels based on Pu^{-239} can be used to support risk management decisions by delineating spatial areas where activity concentrations can be regarded as acceptable. Simply stated, exposure to compounds at concentrations equal to or less than the reference level can be considered safe from an added cancer risk perspective.

The surface soil reference levels developed in this report are based on the most conservative end of EPA's risk range. This conservative calculation of reference levels is prudent to provide interim guidance until completion of the OU 3 RCRA Facilities Investigation/Remedial Investigation (RFI/RI) Report in early 1994.

1 In the Remedy Report, the generic risk assessment was a conservative upper-bound assessment that did not reflect EPA's intent in calculating risk based on the Reasonable Maximum Exposure (RME) concept. RME should be comprised of a product of factors, such as concentration and exposure frequency and duration, that are an appropriate mix of values that reflect averages and 95th percentile distributions (EPA, 1990). EPA recognizes the need for professional judgement and offers guidance that the RME should estimate a conservative exposure scenario that is within the range of possible exposures (EPA, 1989). Additionally, RME represents a single "point estimate." Point estimates normally suffice for making bounding case risk management decision, they suffer however, from not presenting insight into alternative assessments. Thus, the current practice in risk assessment is to develop and present several relevant alternative scenarios for scrutiny.

2.0 METHODOLOGY

2.1 PLUTONIUM AS THE INDICATOR FOR ESTABLISHING SURFACE SOIL REFERENCE LEVELS

As an indicator for establishing reference levels to identify the OU 3 AOC, the following is considered: 1) there are a many Pu^{-239} surface soil measurements in OU 3; 2) Pu^{-239} is regarded by EPA as a human carcinogen and exposure to this compound is considered significant; and 3) the risk contribution from its principal decay product, Am^{-241}, can be readily incorporated.

2.2 REVIEW OF THE FINAL REMEDY REPORT

In the Remedy Report (DOE, 1991), DOE reported generic risks for hypothetical recreational and residential exposure scenarios that could arise from exposure to Pu^{-239} in surface soils. Both scenarios were conservatively assessed with a small chance that actual risks could exceed the reported risk values. A summary of these risk estimates are shown in Table 2.2-1.

Table 2.2-1 Conservative Exposure Scenario LECR-M Values as Calculated in the Final Remedy Report.

Exposure Scenario	LECR-M at 1 pCi/gm Pu^{-239}
Recreational	7.0E-8
Residential	2.2E-7
Source: DOE 1991	

Table 2.2-1 indicates that, under conservative assumptions including long-term exposure (i.e., 40 years recreational and 30 years residential exposure periods), a nominal 1 pCi/g Pu^{-239} surface soil activity concentration could present upperbound lifetime excess cancer mortality risks (LECR-M) of 7.0E-8 for recreational use and 2.2E-7 assuming residential use[2]. Although these are conservative estimates, the LECR-M in Table 2.2-1 does not reflect the added risk that would be contributed from Am^{-241}. Am^{-241} is always present with Pu^{-239} as a result of radioactive decay.

Pathway component contribution is a significant factor to consider when identifying AOCs based on concentrations of Pu^{-239} in surface soils. Therefore, risk contribution profiles are presented for the various pathways reported in the Remedy Report (DOE, 1991). Pathway contribution profiles for the Conservative Recreational Exposure are shown in Table 2.2-2; Table 2.2-3 shows contributions for the Conservative Residential Exposure scenario.

2 For perspective, these LECR-Ms represent increases in risk of 1 in 14 million (i.e., recreational) and 1 in 4.5 million (i.e., residential). As discussed in the Remedy Report (DOE, 1991), these LECR-M's are below EPA's threshold for acceptable risk which is normally quoted as 1E-6 to 1E-4 (i.e., 1 in 1 million to 1 in ten thousand).

Table 2.2-2 Pathway Contribution Profile Conservative Recreational Exposure Scenario as Calculated in the Final Remedy Report.

Pathway	Pu^{-239} Soil Concentration 1 pCi/gm	10 pCi/gm	100 pCi/gm	Percent Contribution
Inhalation of Dust	7E-8	7E-7	7E-6	96.5
Ingestion of Soil	2E-9	2E-8	2E-7	3.5
Total Risk:	7E-8	7E-7	7E-6	100
Source: DOE 1991				

As indicated in Table 2.2-2, inhalation of resuspended dust was identified as the major contributing pathway (i.e., about 97 percent) to risk for the recreational scenario in the Final Remedy Report.

Table 2.2-3 Pathway Contribution Profile Conservative Residential Exposure Scenario as Calculated in the Final Remedy Report.

Pathway	Pu^{-239} Soil Concentration 1 pCi/gm	10 pCi/gm	100 pCi/gm	Percent Contribution
Ingestion of Soil	4.1E-8	4.1E-7	4.1E-6	18.7
Inhalation of Dust	3.0E-8	3.0E-7	3.0E-6	13.8
Ingestion of Leafy Vegetables	1.1E-7	1.1E-6	1.1E-5	51.9
Ingestion of Tuber Vegetables	3.3E-8	3.3E-7	3.3E-6	15.3
Ingestion of Beef Muscle	4.0E-10	4.0E-9	4.0E-8	0.2
Ingestion of Beef Liver	4.1E-10	4.1E-9	4.1E-8	0.2
Ingestion of Milk	3.3E-12	3.3E-11	3.3E-10	>0.1
Total Risk	2.2E-7	2.2E-6	2.2E-5	100

Table 2.2-3 indicates that ingestion of leafy vegetables (e.g., lettuce) was predicted to be the dominant pathway (i.e., this contributed approximately 52 percent of the added risk) in the Final Remedy Report. Other significant pathways in Table 2.2-3 are the incidental ingestion of soil, the ingestion of tuber type vegetables (e.g., potatoes), and the inhalation of resuspended dust. Together these four pathways contribute over 99 percent of the total risk in the Conservative

Residential Exposure Scenario. Consequently, the pathway contribution presented in Table 2.2-3 was used as the basis for estimating soil reference levels. DOE is evaluating the various residential scenario pathway contributions. The Final RCRA Facility Investigation/Remedial Investigation (RFI/RI) Work Plan for OU 3 (DOE, 1992), emphasized contribution from inhalation of resuspended particulate as the most important exposure pathway. It is possible that the forthcoming Draft OU 3 RFI/RI report will reflect a different pathway contribution profile.

2.3 PU-239 BASED REFERENCE LEVELS

The October 1992 Draft version of this report used the Remedy Report risk estimates to back-calculate Pu^{-239} soil activity concentration reference levels while including the presence of Am^{-241} from radioactive decay. To calculate risk-based, soil thresholds for a single species (e.g. Pu^{-239} only) for an LECR-M of 1.0E-6, a simple linear back-calculation methodology based on proportionality between soil concentration and risk is normally used. For example, using the Final Remedy Report Conservative Recreational Exposure LECR-M of 7.0E-8 for 1 pCi/g Pu^{-239} (See Table 2.2-1), a 1.0E-6 reference level of 14.3 pCi/g Pu^{-239} soil activity concentration may be estimated as shown below:

$$1.0E\text{-}6 \text{ LECR-M Ref. Level} = 7.0E\text{-}8 \text{ LECR-M Ref. Level} \bullet \left(\frac{1.0E\text{-}6}{7.0E\text{-}8}\right)$$

$$1.0E\text{-}6 \text{ LECR-M Reference Level} = 1 \text{ pCi/gm} \bullet \left(\frac{1.0E\text{-}6}{7.0E\text{-}8}\right)$$

$$1.0E\text{-}6 \text{ LECR-M Reference Level} = 14.3 \text{ pCi/gm}$$

Reference values based on 1E-5 and 1E-4 (i.e., acceptable risk alternatives still within the EPA's risk range) would be 143 pCi/g and 1,430 pCi/g respectively. Thus, the stated acceptable risk is a major variable in establishing reference levels. The use of this 100-fold risk range (i.e., 1E-6 to 1E-4) is prescribed in the National Contingency Plan (NCP) (EPA, 1990). EPA guidance does not recommend remedial action for sites with risks less than 1E-4 (EPA, 1991).

By this method, reference levels in the October 1992 Draft version of this report were estimated as a baseline level from which the presence of Am^{-241} might be considered. However, when considering LECR-M as additive (according to EPA policy), this approach results in a reference level that is too high because the added risk from Am^{-241} (that exists when Pu^{-239} is present) has not been considered. As a result, the Pu^{-239} reference level of 14.3 pCi/g must be lowered when the Am^{-241} is included. As illustrated in Section 2.4, this adjustment results in an approximate 20 percent lowering (i.e., a reduction in allowable contamination) of the Pu^{-239} reference level.

2.4 CONSIDERATION OF AM-241 IN-GROWTH

Am^{-241} can have a significant impact in the characterization of risk and attendant reference levels. Comparing cancer slope factors indicates that Am^{-241} is of roughly the same potency as Pu^{-239} by the ingestion and inhalation routes. In the October 1992 Draft version of this report, EPA potency factors indicated a significant difference in ingestion potencies (Am^{-241} was regarded as approximately 10 times more potent via ingestion). Cancer slope factors for Pu^{-239} and Am^{-241} used in this report are shown in Table 2.4-1.

Table 2.4-1 Cancer Slope Factors

	Pu^{-239}	Am^{-241}
Ingestion Slope Factor	2.3E-10/pCi	2.4E-10/pCi
Inhalation Slope Factor	3.8E-8/pCi	3.2E-8/pCi
Source: EPA 1991		

Am^{-241} dose and risk component was included in developing the reference levels by: 1) establishing the empirical relationship between Am^{-241} and Pu^{-239} in OU 3 surface soils using measured data from Jefferson County (JeffCo, 1991); and 2) considering the cancer risk increment from potency factors between Pu^{-239} and Am^{-241}.

Linear regression on co-located samples analyzed for Am^{-241} and Pu^{-239} estimated the following activity concentration relationship:

$$Am^{-241} = 0.156 * Pu^{-239} + 0.036;\ R^2 = 0.89,\ n = 48\ pairs.$$

This approximate relationship was also predicted by Krey et al. (1976) and is close to the ingrowth predicted by theoretical decay relationships. In essence, this regression relationship predicts that for the activity concentrations of Pu^{-239} found in OU 3, one would expect an Am-241 activity concentration of approximately 19 percent. For example, if the measured surface soil Pu^{-239} activity concentration were 1 pCi/g, the expected Am^{-241} would be approximately 0.19 pCi/g. Consideration of the Am^{-241} ingrowth, ingestion potency factors, and relative pathway contribution typically results in an approximate 20 percent overall reduction in Pu^{-239} based soil reference levels. Appendix A contains a sample calculation illustrating the adjustment process.

3.0 RESULTS

3.1 PRELIMINARY REASONABLE MAXIMUM EXPOSURE REFERENCE LEVELS BASED ON PU^{-239} AND AM^{-241} INGROWTH

Preliminary reference levels (based on Pu-239 soil concentrations) for the Generic Remedy Report Case (as reported in October 1992, for comparison purposes only) and several alternative Reasonable Maximum Exposure Cases (RME)[3] are presented for recreational (See Table 3.1-1) and residential (See Table 3.1-2) scenarios. For comparison purposes, reference levels computed in the October 1992 draft are presented alongside more recent computations that address changes in EPA's cancer slope factors. Computation spreadsheets that include references to assumptions used in these calculations are included as Table A and B in Appendix A. Major differences in input parameters for the exposure variables are included under the heading of "Basis" for each Case.

[3] DOE is not presenting an official OU 3 RME, nor are the subject reference levels intended as Preliminary Remediation Goals (PRG). Both the RME and PRGs will be addressed formally in the RFI/RI, CMS/FS process.

Overall, each case (A, B, C, D, etc.) is progressively less restrictive. This is indicated by the successive increase in the reference levels.

Table 3.1-1 Preliminary RME Reference Levels Pu^{-239} Surface Soil Activity Concentrations Giving a 1.0E-6 LECR-M Considering Am^{-241} Ingrowth in the Recreational Scenario

Case/Basis	October 1992 Reference Level pCi/gm	Revised 1993 Reference Level pCi/gm
Remedy/40 Year, Very Conservative	10.8	7.2
A/30 Year, Very Conservative	14.4	9.6
B/9 Year, 40 Day, Conservative	80.6	44.7
C/9 Year, 20 Day, Conservative	134	89
D/9 Year, 20 day, 90 mg/Day, Conservative	**137**	**100**
E/3 Year, 20 Day, 90 mg/Day, Conservative	403	301
BOLD = DOE's Preferred Risk Management Values. LECR-M = Lifetime Excess Cancer Risk for Mortality.		

Table 3.1-2 Preliminary RME Reference Pu^{-239} Surface Soil Activity Concentrations Giving a 1.0E-6 LECR-M Considering Am^{-241} Ingrowth in the Residential Scenario

Case/Basis	October 1992 Reference Level pCi/gm	Revised 1993 Reference Level pCi/gm
Remedy/30 year, Very Conservative	0.45	0.6
A/9 Year, Conservative	1.3	1.7*
B/9 Year, 60 mg/Day	**2.6**	**3.5***
C/9 Year, 60 mg/Day, Fractional Exposure Period	4.2	6.4

BOLD = DOE's Preferred Risk Management Values.

LECR-M = Lifetime Excess Cancer Risk for Mortality.

Note: The October 1992 residential scenario numbers in Table 3.1-2 were misstated due to a minor computational error.

*A similar computation performed by EPA, and adjusted down by 20% to account for Am^{-241}, provides a soil reference level of about 5.1 pCi/gm. Considering the uncertainty associated with theory based computations, these estimates are in general agreement.

Table 3.1-1 shows a Case D RME based surface soil reference level of 100 pCi/g Pu^{-239} assuming a **recreational exposure scenario**. This soil reference value reflects the approximate RME for the anticipated land use foreseen at OU 3. This is the soil activity concentration of Pu^{-239} that corresponds to 1E-6 LECR-M considering the concurrent dose and risk Pu^{-239} and Am^{-241} [4]. DOE elects to set this surface soil reference at the most conservative portion of EPA's risk range at this time (i.e., 1E-6) because it is unclear what the actual land use determination for OU 3 will be. In contrast, a reference level using the most conservative Remedy Report assumptions for a recreational exposure scenario would be about 7.2 pCi/g Pu^{-239}.

A review of Table 3.1-2 indicates a Case B RME-based surface soil reference level of 3.5 pCi/g Pu^{-239} using a residential exposure scenario. Similar to the recreational scenario, this is the soil activity concentration of Pu^{-239} that corresponds to 1E-6 LECR-M considering the concurrent dose and risk from Pu^{-239} and Am^{-241}. Like the recreational scenario, DOE feels that identifying a surface soil reference at the most conservative portion of EPA's risk range (i.e., 1E-6) is prudent at this time because it is not clear how the OU 3 area will actually be used. In contrast to the 3.5 pCi/g reference level, a reference level using the most conservative Remedy Report assumptions (for a residential exposure scenario) would be about 0.6 pCi/g.

A map identifying the approximate locations of 1, 5, and 10 pCi/gram Pu^{-239} isocontours on the east side of the Rocky Flats Plant (RFP) is included in Appendix C. Given the range of reference levels identified in this report, the 1, 5, and 10 pCi/g isocontours provide a relative indication of the AOC.

[4] This value assumes that LECR-Ms are additive and is in accordance with EPA guidance. The premise of additivity has never been validated.

The reference levels in Tables 3.1-1 and 3.1-2 (i.e., RME or Remedy Report) were computed using the most conservative portion of EPA's guidance for radiation risk assessment (EPA, 1989). Use of more traditional health-physics risk analysis methods (presented in EPA guidance, 1989) and used by EPA to estimate annual doses from chronic exposure to radionuclides in surface soils in the vicinity of RFP (Burley, 1990)) would have produced higher (i.e., less conservative) reference levels. For example, the Pu^{-239} surface soil activity concentration associated with a dose of 100 mrem/yr. is estimated to be approximately 300 pCi/g[5]. Given a total average annual effective dose equivalent of 360 mrem/yr. to the U.S. population, the additional contribution from the OU 3 AOC is very small.

The recreational scenario assumptions used to develop the RME based surface soil reference level of 100 pCi/gram Pu^{-239} also developed values for a variety of exposure conditions. This satisfied the requirement that the RME be a mixture of conservative and central tendency exposure parameters (See Footnote 3). Tables 3.1-1 indicates that, depending on exposure assumptions used, reference level estimates ranged from 7.2 pCi/g to 301 pCi/g for the recreational scenario. In the residential scenario (See Table 3.1-2), reference levels range from 0.6 pCi/g to 6.4 pCi/g depending on selection of exposure assumptions. Review of Tables 3.1-1 and 3.1-2 indicates that: (1) Remedy Report input assumptions, with one exception, are all conservative, upper-bound estimates and, (2) RME input assumptions reflect a mix of conservative and central tendency values. Notable in the RME case is that exposure concentration (i.e., soil activity concentration of Pu^{-239}) the master variable in these calculations, was fixed at the conservative Remedy Report value. Overall, the RME based reference level reflects EPA guidance while the Remedy Report-based estimates approximate a worst-case setting[6].

4.0 DISCUSSION

The potential for future land use is an important consideration when applying reference levels in a risk-management frame work. Comparing the revised reference levels from Table 3.1-1 for a **recreational use scenario** with isoconcentration lines on the Map from Appendix C indicates:

- None of the reference levels; which range from 7.2 pCi/g to 301 pCi/g, would be expected to be consistently detected in OU 3[7].
- This comparison would suggest that unless the RFI/RI Report discloses significant new contamination, recreational use of OU 3 lands should not present LECR-M above EPA's risk range of (1E-6 to 1E-4).

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[5] For reference, 100 mrem/year is the recommended dose limit for members of the public established by the National Council on Radiation Protection (NCRP, 1987) and DOE Order 5400.5 (DOE 1990).

[6] Previous guidance required developing an upper-bound estimate, however, that practice has been abandoned partly because the upper-bound estimates were implausible and could not be regarded as credible.

[7] The isoconcentration lines are approximate and should be used with knowledge that they are indicative of the general trend and some variation will occur. For example, the highest single surface soil concentration of Pu^{-239} known to exist in OU 3 is approximately 8 pCi/gm.

- Even under the most conservative assumptions of the six cases presented, no recreational scenario AOC exists in OU 3.

- A more reasonable recreational scenario-based surface soil reference level is 100 pCi/g Pu^{-239} which should be used for comparative purposes in risk management decisions.

A similar comparison between the Table 3.1-2 **residential scenario** reference levels and the map from Appendix C indicates that:

- The 5 pCi/g isoconcentration contour does not extend beyond the RFP boundary; the 1 pCi/g isoconcentration contour extends past RFP and just south of Great Western Reservoir.

- Pu^{-239} activity concentration is less than 1 pCi/g on the vast majority of OU 3 lands.

- Nearly all of OU 3 is below the residential scenario reference level of 3.5 pCi/g Pu^{-239}.

It is important to acknowledge the conservatism reflected in this analysis and in particular the selection by DOE of a 1E-6 risk threshold for identifying reference levels and AOCs. The NCP instructs EPA to consider the risk range of 1E-6 to 1E-4 as acceptable when making risk management decisions. Additionally, guidance issued by the Agency suggests that remedial action to reduce risk below 1E-4 generally is not warranted. Thus, the AOCs calculated in this report are 100 times more conservative than a comparable assessment to determine remedial alternatives under CERCLA.

APPENDIX A

Appendix A

Method of Incorporating Am-241 Ingrowth into LECR-M Calculations for OU3

The linear regression formula of JeffCo (1991),

$$[Am^{241}] = 0.156*[Pu^{239}]+0.036,$$

enables estimation of Am^{-241} soil activity concentration (SAC) based on knowledge of Pu^{-239} SAC. Specifically, this equation predicts 0.19 pCi/gm SAC fors Am^{-241} when the measured Pu^{-239} SAC is is on the order 1.0 pCi/gm. This relationship is in good agreement with predictions by Krey et al. (1979).

As a reasonable simplification for the purposes of this discussion, the ratio of Pu^{-239} to Am^{-241} activity concentrations is assumed to be fixed and constant at 1:0.19. Furthermore, this ratio is assumed fixed regardless of OU3 soil condition and constant through both time and environmental transport processes. Consequently, if a model scenario in this report predicts 0.001 pCi of Pu^{-239} from OU3 soils inhaled or ingested by a receptor, this discussion assumes a corresponding 0.00019 pCi of Am^{-241} from OU3 soils is also inhaled or ingested.

Because pathway transport is assumed identical with respect to activity for these two radionuclides (by the constant activity ratio of 1:0.19) and because slope factors for carcinogenic effects are functions of activity (Risk/pCi), health risks for both radionuclides are simply related by

$$Am\text{-}241\,Risk = (Pu\text{-}239\,Risk)*\left(\frac{Am\text{-}241\,SlopeFactor}{Pu\text{-}239\,SlopeFactor}\right)*(0.19)$$

with appropriate slope factors for either the inhalation or ingestion route of exposure.

As an example, consider the Remedy Report Recreational Exposure scenario. In this model, incidental inhalation of Pu^{-239} dust and incidental ingestion of Pu^{-239} from OU3 soils with a Pu^{-239} SAC of 1 pCi/gm are predicted to result in 6.2E-8 and 5.9E-8 LECR-Ms respectively with a total LECR-M of 1.2E-7. Assuming, then, that this same scenario also contains incidental inhalation and ingestion of Am^{-241} from OU3 soils (with 0.19 pCi/gm Am^{-241} SAC) LECR-Ms due to Am^{-241} for both routes are easily determined with the use of slope factors from EPA (1992). The risk per 0.19 pCi/gm SAC of Am^{-241} in OU3 soils under the Remedy Report

Recreation Exposure model due to incidental inhalation is

$$Am\text{-}241\,Risk_{inh} = (6.2E\text{-}8) * \left(\frac{3.2E\text{-}8}{3.8E\text{-}8}\right) * (0.19)$$

$$Am\text{-}241\,Risk_{inh} = 9.9E\text{-}9$$

and the risk due to incidental ingestion is

$$Am\text{-}241\,Risk_{ing} = (5.9E\text{-}8) * \left(\frac{2.4E\text{-}10}{2.3E\text{-}10}\right) * (0.19)$$

$$Am\text{-}241\,Risk_{ing} = 1.2E\text{-}8$$

with a total Am^{-241} LECR-M contribution of
9.9E-9 (by inhalation) + 1.2E-8 (by ingestion) = 2.2E-8.

The Total LECR-M, then, per 1 pCi/gm SAC of Pu^{-239} and 0.19 pCi/gm SAC of Am^{-241} on OU3 soils under the Remedy Report Recreation Exposure model is [1.2E-7(Pu^{-239}) + 2.2E-8(Am^{-241})] = 1.4E-7.

Therefore, to meet the 1.0E-6 ELCR goal under the Remedy Report Recreation Exposure model, OU3 soils must contain no more than 7.0 pCi/gm SAC Pu^{-239} and 1.4 pCi/gm Am^{-241} because 1.4E-7 may be divided into 1.0E-6 about 7 times.

This same methodology has been used to incorporate Am^{-241} ingrowth and health effects into all scenarios discussed in this report. The end result of the consideration of Am^{-241} is that LECR-M remains at 1.0E-6 and Pu^{-239} concentrations are reduced about 15% to make room, so to speak, for Am^{-241} risk contribution.

TABLE A, SUMMARY OF ALTERNATIVE SURFACE SOIL ACTIVITY CONCNETRATION ESTIMATES AND REFERENCES -RECREATIONAL SCENARIO

Pathway Contributions Based on the Recreational Exposure Scenario in the Remedy Report

Major Risk-Exposure Assessment Input Variables

The number in parentheses (7.2 pCi/gr) is the estimated Pu-239 soil reference level giving a 1E-6 LECR-M including full Am-241 ingrowth.

Variable	Remedy Report (7.2 pCi/gr)	Category/ Ref.	Case A (9.6 pCi/gr)	Category/ Ref.	Case B (44.7 pCi/gr)	Category/ Ref.	Case C (89 pCi/gr)	Category/ Ref.
Susp. Particulate	73 ug/m^3	Consrv/(1)	73 ug/m^3	Consrv/(1)	73 ug/m^3	Consrv/(1)	73 ug/m^3	Consrv/(1)
Inhalation Rate (2)	10 m^3/day	Consrv/(2)	10 m^3/day	Consrv/(2)	10 m^3/day	Consrv/(2)	10 m^3/day	Consrv/(2)
Annual Exposure Days/Year	56 day/yr	Consrv/(3a)	56	Consrv/(3a)	40 day/yr	Consrv/(3b)	20 day/yr	Cen Tend/(3c)
Exposure Period	40 yr	Consrv/(4a)	30	Consrv/(4b)	9 yr	Cen Tend/(4c)	9 yr	Cen Tend/(4c)
Incidental Soil Ingestion	115 mg/day	Consrv/(5a)	115 mg/day	Consrv/(5a)	115 mg/day	Consrv/(5a)	115 mg/day	Consrv/(5a)

Variable	Case D (100 pCi/gr)	Category/ Ref.	Case E (301 pCi/gr)	Category/ Ref.
Susp. Particulate	73 ug/m^3	Consrv/(1)	73 ug/m^3	Consrv/(1)
Inhalation Rate (2)	10 m^3/day	Consrv/(2)	10 m^3/day	Consrv/(2)
Annual Exposure Days/Year	20 day/yr	Cen Tend/(3c)	20 day/yr	Cen Tend/(3c)
Exposure Period	9 yr	Best. Est./(4c)	3	Cen Tend/(4d)
Incidental Soil Ingestion	90 mg/day	Consrv/(5b)	90 mg/day	Consrv/(5b)

Note Soil Fraction @ 1 (corrected) from Remedy Report causing a small increase in RR risk (7E-8 tO 7.4E-8 @ 1 pCi/gr)

See second page for references

TABLE A, SUMMARY OF ALTERNATIVE SURFACE SOIL ACTIVITY CONCNETRATION ESTIMATES AND REFERENCES -RECREATIONAL SCENARIO

Pathway Contributions Based on the Recreational Exposure Scenario in the Remedy Report

Major Risk-Exposure Assessment Input Variables

The number in parentheses (7.2 pCi/gr) is the estimated Pu-239 soil reference level giving a 1E-6 LECR-M including full Am-241 ingrowth.

TABLE A, SUMMARY OF ALTERNATIVE SURFACE SOIL ACTIVITY CONCNETRATION ESTIMATES AND REFERENCES -RECREATIONAL SCENARIO

Conservative in the recreational setting where:

1. 73/37=double long-term RFP TSP actuals

2. Assumes 50% of daily volume occurs @ OU3 (essentially

3a. 2 day/week, 4 week/mo., 7 mo./year (avg Temp> 40F. AMJJASO) (NOAA, 1987)

3b. 2 day/week, 4 week/mo., 5 mo./year (avg Temp> 60F. MJJAS) (NOAA, 1987)

3c. 1 day/week, 4 week/mo., 5 mo./year (avg Temp> 60F. MJJAS) (NOAA, 1987)

4a. 40 year exceeds the upper 90th%-tile estimate (EFH, EPA, 1989) for sustained residence

4b. 30 year is 90%-tile estimate (EFH, EPA, 1989) for sustained residence

4c. 9 year is the 50%-tile estimate (EFH, EPA, 1989) for sustained residence.

4d. 3 year is the best estimate for expected recreational use before the ROD.

5a. 115 mg/day is essentially 120 mg/day, upper-bound (OSWER 9285.6-03, EPA 1991)

5b. 90 mg/day, average-case is 1.5 X the 60 mg/day residential central tendancy (LaGoy 1987)

TABLE B, SUMMARY OF ALTERNATIVE SURFACE SOIL ACTIVITY CONCNETRATION ESTIMATES AND REFERENCES -RESIDENTIAL SCENARIO

Pathway Contributions Based on the Residential Exposure Scenario in the Remedy Report

Major Risk-Exposure Assessment Input Variables

The number in parentheses (0.6 pCi/gr) is the estimated Pu-239 soil reference level giving a 1E-6 LECR-M including full Am-241 ingrowth.

Variable	Remedy Report (0.6 pCi/gr)	Category/ Ref.	Case A (1.7 pCi/gr)	Category/ Ref.	Case B (3.5 pCi/gr)	Category/ Ref.	Case C (6.4 pCi/gr)	Category/ Ref.
Surface Soil Activity/Conc.	1.0 pCi/gr	Consrv/(1)	1.0 pCi/gr	Consrv/(1)	1.0 pCi/gr	Consrv/(1)	1.0 pCi/gr	Consrv/(1)
Inhalation Rate (2)	20 m^3/day	Consrv/(2)	20 m^3/day	Consrv/(2)	20 m^3/day	Consrv/(2)	20 m^3/day	Consrv/(2)
Annual Exposure Days/Year	365 day/yr	Consrv/(3)	365 day/yr	Consrv/(3)	365 day/yr	Consrv/(3)	365 day/yr	Consrv/(3)
Exposure Period	30 yr	Consrv/(4a)	9 yr	Cen Tend/(4b)	9 yr	Cen Tend/(4b)	9 yr	Cen Tend/(4b)
Incidental Soil Ingestion	120 mg/day	Consrv/(5a)	120 mg/day	Consrv/(5a)	60 mg/day	Cen Tend/(5b)	60 mg/day	Cen Tend/(5b)
Intake of Leafy Vegetables	33 gr/day	Cen Tend(6a)	50 gr/day	Cen Tend(6b)	50 gr/day	Cen Tend(6b)	50 gr/day	Cen Tend(6b)
Intake of Tubor & Fruit	89 gr/day	V-Consrv/(6c)	42 gr/day	Consrv/(6d)	42 gr/day	Consrv/(6d)	42 gr/day	Consrv/(6d)
Dust Load-Scrub Fraction	0.01	Consrv/(7a)	0.01	Consrv/(7a)	0.005	Cen Tend(7b)	0.005	Cen Tend(7b)
Root Uptake-Scrub Fraction	0.001	Consrv/(7c)	0.001	Consrv/(7c)	0.000001	Cen Tend(7d)	0.000001	Cen Tend(7d)
Fractional Time @ Home	1	Consrv/(8a)	1	Consrv/(8a)	1	Consrv/(8a)	0.64	Cen Tend (8b)
Fraction of Households w/ gardens	1	Consrv/(9a)	1	Consrv/(9a)	1	Consrv/(9a)	0.53	Cen Tend (9b)

TABLE B, SUMMARY OF ALTERNATIVE SURFACE SOIL ACTIVITY CONCNETRATION ESTIMATES AND REFERENCES -RESIDENTIAL SCENARIO

Footnotes for Table B

Conservative in the residential setting where:

1. Soil mixing from construction, tilling for a garden and general anthropogenic activity would reduce the soil concentration.
   All Scenario's Are Overestimated By: 2 to 3 (Illsley, 1987)

2. 20 m^3/day, reasonable upper-bound (OSWER 9285.6-03, EPA 1991)

3. 365 day/year is a worst-case estimate

4a. 30 year is the upper 90th%-tile estimate (EFH, EPA, 1989)

4b. 9 year is 50%-tile estimate (EFH, EPA, 1989)

5a. 120 mg/day, upper-bound (OSWER 9285.6-03, EPA 1991)

5b. 60 mg/day, average-case (LaGoy 1987)

6a. 33 gr/day is slightly less than typical (50 gr/day) (EFH,EPA, 1989)

6b. 50 gr/day is typical (EFH, EPA, 1989) correction made.

6c. 89 gr/day is double the reasonable worst-case (42 gr/day) (EFH, EPA, 1989)

6d. 42 gr/day reasonable worst-case (EFH, EPA, 1989)

7a. Fraction of soil concentration applied to leafs w/scrub-off , 0.01 conservative (Burley, EPA, 1990)

7b. Fraction of soil concentration applied to leafs w/scrub-off, 0.005 middle of range (Burley, EPA, 1990)

7c. Fraction taken-up w/ scrub-off. Top of range (Burley, EPA 1990)

7d. Fraction taken-up w/ scrub-off. Middle of range (Burley, EPA 1990)

8a. Maximum fractional time @ residence: 1 , affects inhalation only, (EFH, EPA 1989)

8b. Average fractional time @ residence: 0.64 , affects inhalation only, (EFH, EPA 1989)

9a. Maximal fraction of housholds w/ gardens: 1, affects food consumption only, (EFH, EPA, 1989)

9b. Maximal fraction of housholds w/ gardens: 0.53, affects food consumption only, (EFH, EPA, 1989)

APPENDIX B

APPENDIX B

STATISTICAL COMPARISON OF CURRENT AND HISTORICAL DATA

Four data sources are used to calculate the isocontour locations on the attached map. These four data sources report soil sampling results from the property known as the Settlement Agreement property. Litigation known as the McKay vs. U.S. et al resulted in a 1984 Settlement Agreement which during a ten year litigation period identified offsite areas with surface soils greater than 0.9 pCi/g of Plutonium. As this AOC document identifies a calculated surface soil reference level greater than 0.9 pCi/g Pu^{-239}, the AOC must occur within the Settlement Agreement property. Illsley and Hume (1979) established the boundary of the Settlement Agreement property by sampling 71 locations offsite and adjacent to the RFP boundary. This sampling effort identified two areas above 0.9 pCi/g Pu^{-239}. The four references which report surface soil sampling results on the Settlement Agreement property are Illsley and Hume1977, Illsley 1987, Illsley 1985 and DOE 1991. The locations of the soil samples are shown on the attached map.

Of concern when using historical data is the lack of information to assess quality parameters. Three of the data sources lacked sufficient information to assess quality parameters. The 1991 data set does meet current data quality assurances. Prior to using the data to construct the isocontour map, data from the three "historical" data sources was compared with the 1991 data set. This statistical evaluation found that the data sets were comparable and thus came from the same population. Three comparisons were made to compare data on the Jeffco north and south properties and the City of Broomfield property. To compare the historical data with the current data the following methodology was used.

OBJECTIVE - Compare current (1991) and historical (1977, 1987, 1985) data sets from the north and south Settlement Agreement Lands.

Three comparisons of data are calculated using a two-tailed T test. Data sets and their sources are shown on accompanying pages. All T-test results are also shown.

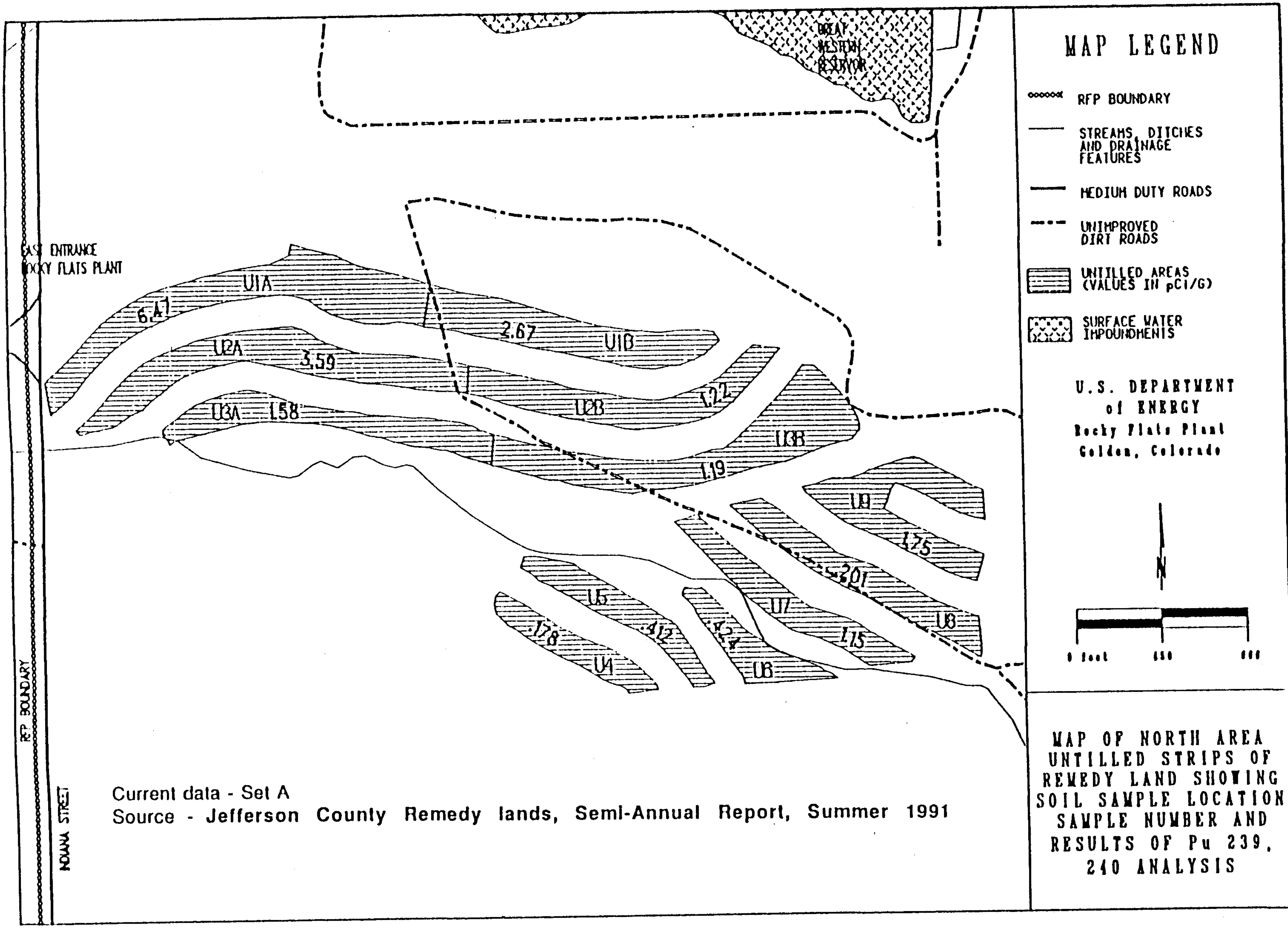
> Comparison #1 - Data set from untilled strips of the north area of Settlement Agreement lands sampled in 1991 vs. 1977 and 1987 data sets from same area. (labeled Set A)
>
> Comparison #2 - Data set from untilled strips of the south area of Settlement Agreement lands sampled in 1991 vs. 1977 and 1987 data sets from same area. (labeled Set B)
>
> Comparison #3 - Data set from untilled strips of the north area of Settlement Agreement sampled in 1991 vs. 1977 and 1987 data sets plus City of Broomfield property sampled in 1985. (labeled Set C)

RESULTS - The data for the plutonium soil samples were categorized into "Historical" (1977, 1987, 1985) and "Current" (1991) classifications. Composite values in pCi/g were entered as data in the two classifications and a T-test was performed on the mean values for each class.

The two-tailed T-test tests the null hypothesis that the mean values for each class are equal against the alternative hypothesis that one class mean is significantly larger than the other. Under the null hypothesis it is assumed that the data were all drawn from one distribution with a variance equal to the pooled sample variance from each class.

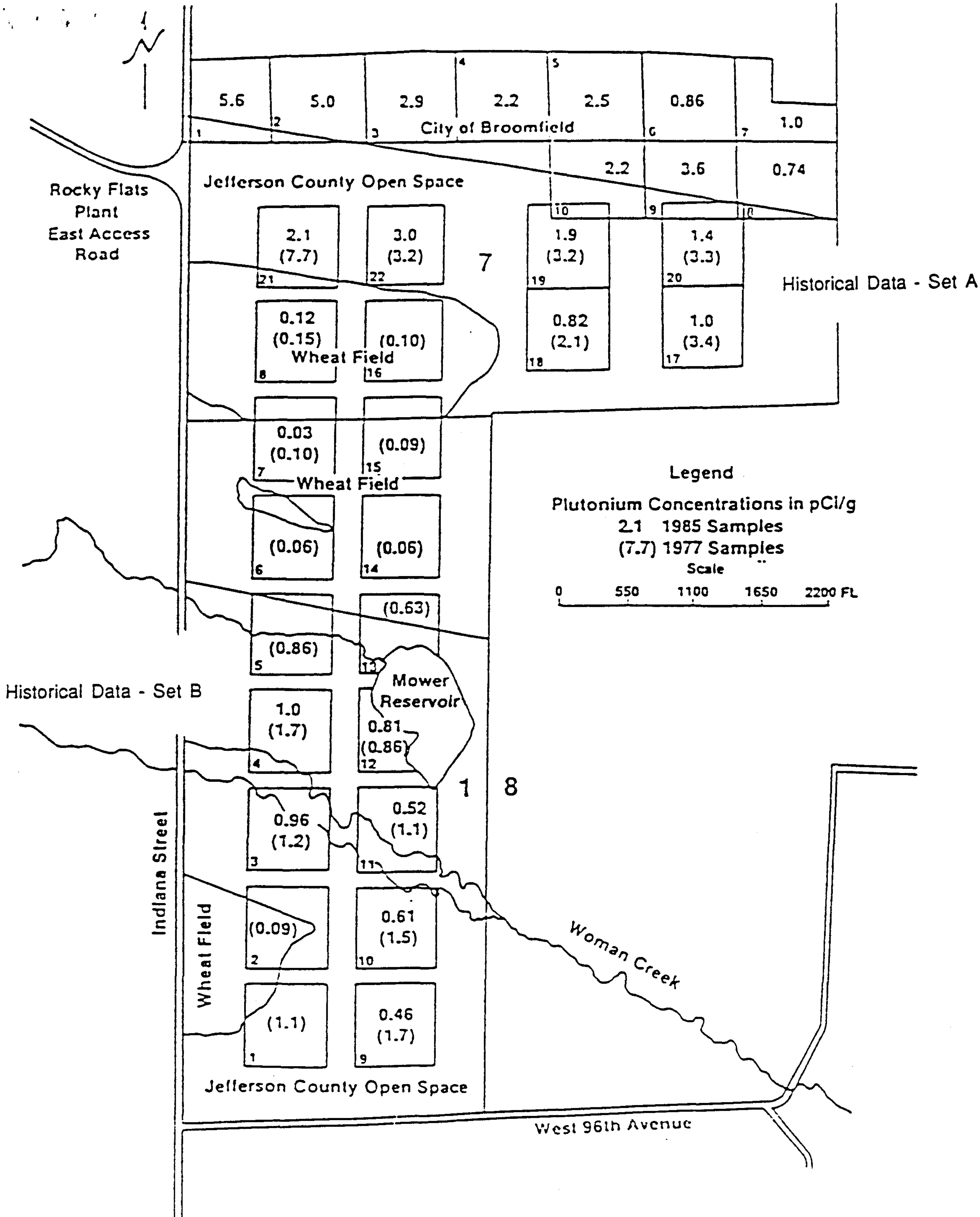
The procedure used for these comparisons was the SAS TTEST. This procedure tests for equal variance and calculates an f-ratio result and significance levels. This procedure also determines significance levels for the T-test when the equal variance assumption is being met and when it is not being met. If the F-test results do not show sufficient evidence to say that the variances are unequal (non-homogenous) then the P-value for un-equal variance should be used as the TTEST procedure makes compensating adjustments. The "equal variance" P-value is used when the data set distributions are similar as indicated by the f-ratio. In each comparison the equal and unequal p-values are similar and the F-test indicates similar distributions.

The level of significance for the T-test is the probability that one would see a difference in means of the magnitude indicated by the printout due to random chance if in fact all the data were drawn from the same population. In all cases the significance level of the test is much larger than 0.05 - the level ordinarily considered to be significant. For all data sets A, B and C the results of the T-test indicates that there is insufficient evidence to conclude that a difference in mean plutonium levels exists between historical and current data.

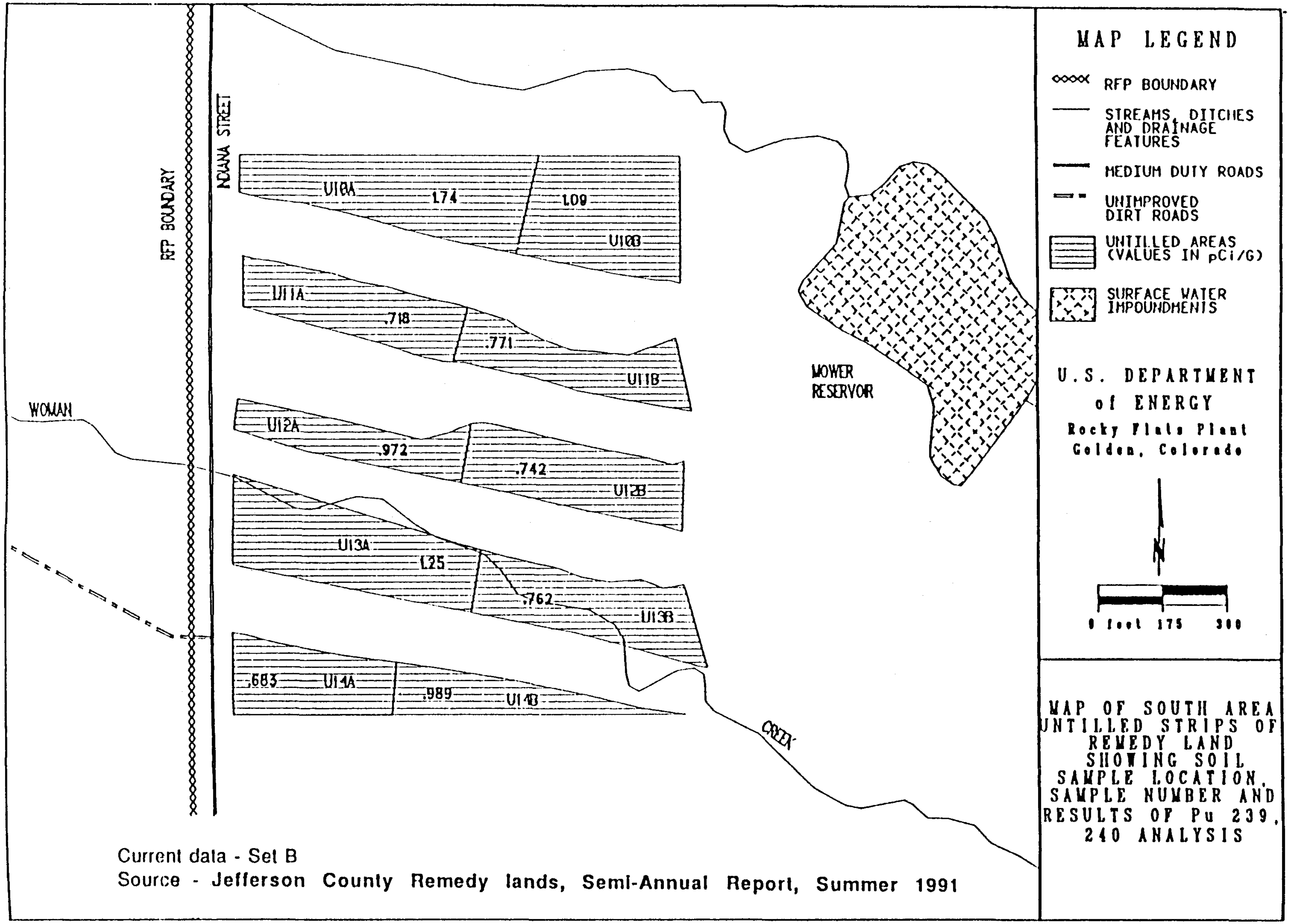


Current data - Set A
Source - Jefferson County Remedy lands, Semi-Annual Report, Summer 1991

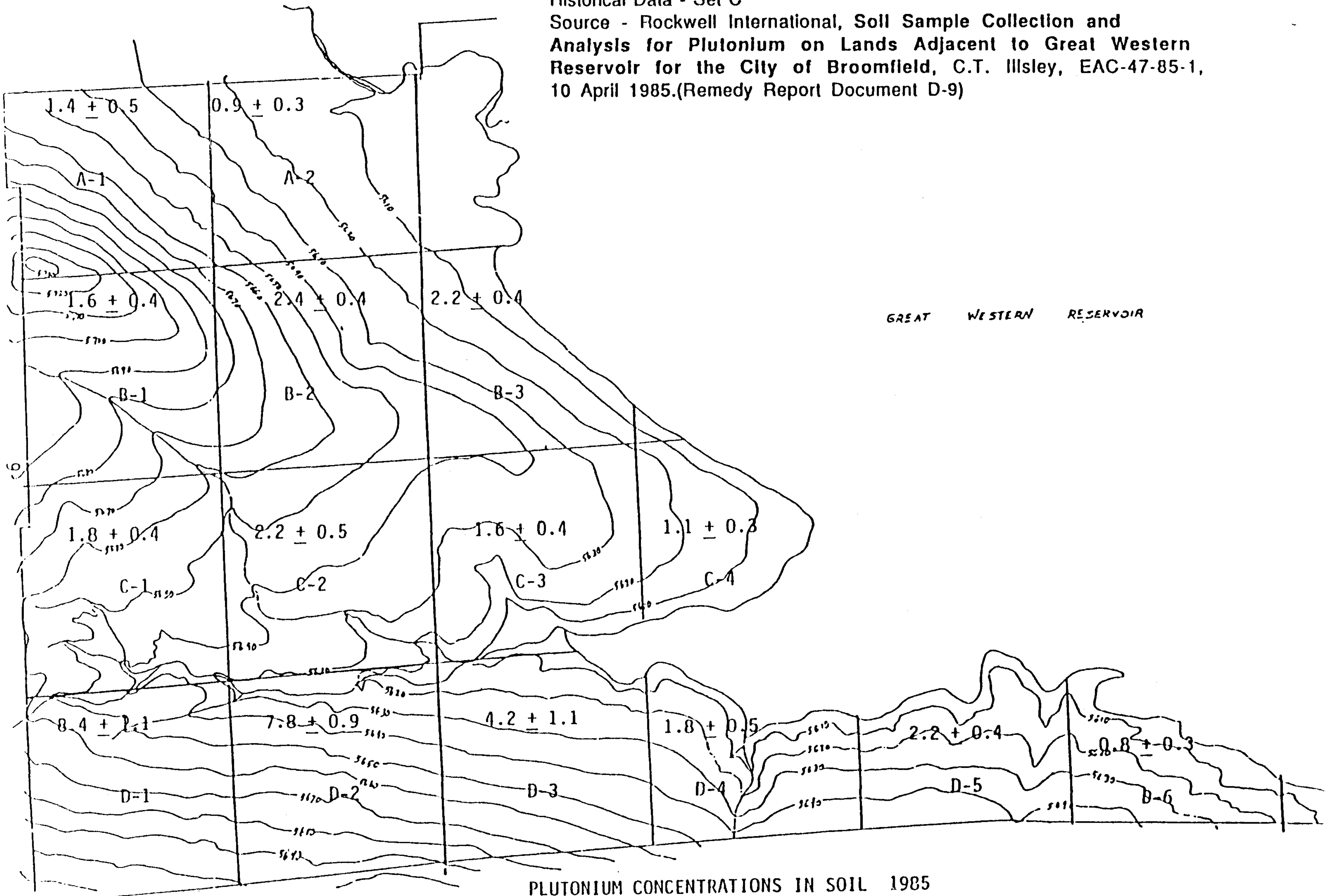
MAP OF NORTH AREA UNTILLED STRIPS OF REMEDY LAND SHOWING SOIL SAMPLE LOCATION SAMPLE NUMBER AND RESULTS OF Pu 239, 240 ANALYSIS



Source - Rockwell International, Remedial Action Program on Jefferson County Open Space Land in Section 7, T2S, R69W, South of Great Western Reservoir, C.T. Illsley, EAC-420-87-1, 15 January 1987. (Remedy Report Document D-10)


MAP LEGEND
RFP BOUNDARY
STREAMS, DITCHES AND DRAINAGE FEATURES
MEDIUM DUTY ROADS
UNIMPROVED DIRT ROADS
UNTILLED AREAS (VALUES IN pCi/G)
SURFACE WATER IMPOUNDMENTS
U.S. DEPARTMENT of ENERGY
Rocky Flats Plant
Golden, Colorado
N
0 feet 175 300
MAP OF SOUTH AREA UNTILLED STRIPS OF REMEDY LAND SHOWING SOIL SAMPLE LOCATION, SAMPLE NUMBER AND RESULTS OF Pu 239, 240 ANALYSIS
RFP BOUNDARY
INDIANA STREET
WOMAN
CREEK
MOWER RESERVOIR
U10A
1.74
1.09
U10B
U11A
.718
.771
U11B
U12A
.972
.742
U12B
U13A
1.25
.762
U13B
.683
U14A
.989
U14B
Current data - Set B
Source - Jefferson County Remedy lands, Semi-Annual Report, Summer 1991

Historical Data - Set C
Source - Rockwell International, Soil Sample Collection and **Analysis for Plutonium on Lands Adjacent to Great Western Reservoir for the City of Broomfield**, C.T. Illsley, EAC-47-85-1, 10 April 1985.(Remedy Report Document D-9)



PLUTONIUM CONCENTRATIONS IN SOIL 1985
(CDM METHOD-UNITS ARE D/M/G)

APPENDIX C

APPENDIX C

MAP CONSTRUCTION

KRIGING THEORY

Use of regionalized variable theory and the semivariogram as a means of describing spatial variation in soils is demonstrated by numerous authors (e.g., Burgess and Webster, 1980a, 1980b; McBratney et al. 1981; Burgess et al., 1981; Gilbert and Simpson, 1985; Webster and Oliver, 1990). The semivariogram describes the rate of change in a regionalized variable and measures the degree of spatial dependence between samples within geographical boundaries (i.e., 2-dimensional analysis) and/or with depth (i.e., 3-dimensional analysis). The spatial structure of the regionalized variable can be described by the semivariogram in the case of stationarity conditions (Bregt et al. 1991). The variogram splits the total variance of a data set into two parts. The first part represents the spatial variance between sample values relative to the distance between samples. The second part represents local or random variance. Because the semivariogram is a function of distance, the weights change according to the spatial arrangement of the samples (Isaaks and Srivastava, 1989).

By definition, the value of the theoretical variogram $\tau(h)$ for a given distance h, is the square of the expected difference (E) between the values of the samples separated by distance h:

$$\tau(h) = E\{Z(x) - Z(x + h)\}^2 \qquad (1)$$

where $Z(x)$ and $Z(x + h)$ are the Pu activities at locations x and $x + h$ separated by the vector h, known as the lag. The experimental semivariogram can be estimated from the data at hand by:

$$\tau(h) = \frac{1}{n(h)} \sum_{i=1}^{n(h)} [Z(x_i) - Z(x_i + h)]^2 \qquad (2)$$

Modeling the experimental semivariogram provides the necessary parameters (i.e., nugget, sill, and range) for interpolation of soil-Pu activities. The calculated variance $\tau(h)$ between samples increases with increasing separation distances up to a distance (A) called the range, where it levels off to a constant value. Samples with a separation distance less than the range are spatially correlated, and those with separation distances greater than the range are statistically independent. The point that the semivariogram levels off is called the sill, and is equal to the overall variance of the sample population. The sill is composed of two components, C and C_0. In most soil environs, $\tau(h)$ will remain nonzero as h approaches zero which is called the nugget effect ($\tau(h)= C_0$, $h > 0$). It reflects the inherent random variation of contaminant dispersion in the environment that cannot be predicted by any method, and may represent the variability between sampling points at distance less than that actually used or available, analytical error, or samples collected from different populations (i.e., depths, soil type, and other edaphic factors).

The kriging interpolation procedure uses the information from the semivariogram to find an optimal set of weights that are used in the estimation of soil-Pu at unsampled locations. The kriging procedure is optimal in the sense that it provides estimates with minimum variance or uncertainty, and this variance can be estimated with a certain degree of confidence. The main sources of the uncertainty estimates are: 1) the number of nearby samples, 2) proximity of the samples, 3) spatial arrangement, and 4) the nature of the contaminant.

Kriging can be applied as a global or local estimator. Globally, the data would be used over the entire site with an estimation of the mean. Local estimation refers to an estimator of the average value of the regionalized variable over smaller soil areas from which a sample is collected. For example, the kriging estimator of the Pu level at a point $Z*(x_0)$ in geographical space is:

$$Z*(x_0) = \sum_{i=1}^{n} \lambda_i Z(x_i) \qquad (3)$$

where $Z(x_i)$ is the observed datum at the point x_i within the local neighborhood about the point x_0, and λ_i is the weight attached to that datum as obtained using a kriging estimator. If the assumptions underlying kriging are met, then the kriging estimator is a best linear unbiased estimator.

The assumptions for simple and ordinary kriging are strong stationarity and minimum kriging variance. These assumptions are expressed as follows:

$$E[Z*(x_0) - Z(x_0)] = 0 \qquad (4)$$

that implies zero drift and

$$Var[Z*(x_0) - Z(x_0)] = \text{a minimum} \qquad (5)$$

The variance in equation 5 provides a measure of the goodness of prediction. The variance depends on the sampling design and the model of the spatial structure of the data.

The assumption of strong stationarity is not always met. For example, Hamlett et al. (1986) showed that the assumption of strong stationarity should always be tested when analyzing the spatial variability of soil attributes. When the stationarity assumption is violated, it is necessary to model the drift function that underlies the semivariogram. In practice, this is achieved by using a universal kriging technique (i.e., non-stationary kriging) that estimates the order of the drift (k), models it, estimates the variogram, and solves the kriging equations (similar to Eq. 3). A complete formalization of the universal kriging is described by Karfritas and Bras (1981).

Geostatistical Approach

The first step to model spatially correlated data was to ascertain the data distribution and reduce the spread of the data using appropriate transformations. Next, a moving-window statistical algorithm was used (Murray and Baker, 1991) to assess the heteroscedasticity of the data. The experimental semivariogram calculations and the best-fit model were developed using GS+ software (Gamma Design Inc. 1991). Cross validation analysis and simple and ordinary kriging computations were performed using the GEO-EAS program (Englund and Sparks, 1988). The universal kriging for three orders of drift was computed using a modified UVKBLK algorithm originally described by Carr (1990). The modification included universal block kriging, five different types of semivariogram models, and numerous code modifications regarding input/output options.

The summary statistics that described the bias and the spread of the error distribution was the Mean Square Error (MSE). The MSE from the kriging estimates was defined as:

$$MSE = 1/n \sum_{i=1}^{n} [Z_i - Z^*_i]^2 \qquad (6)$$

where Z_i was the observed value and Z^*_i was the estimated value. The kriging technique that gave the lowest MSE, the most evenly distributed error map, and the smallest scatter of the observed versus the estimated plot was used for Pu estimation. A computer code was written to compute the MSE, the Mean Kriging Variance (MKV), and the Gaussian confidence limits following the procedure outlined by Bregt et al. (1991). The kriging variances from each estimator were multiplied by the ratio MSE/MKV to compensate for the assumed underestimation of the kriging variance (see Bregt et al. 1991). These adjusted kriging variance estimates were used to determine confidence intervals for each point in the study area using the 90 percent Gaussian confidence limits:

$$Z^* \pm 1.645(\text{adjusted standard deviation}) \qquad (7)$$

APPENDIX D

APPENDIX D

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